Draft
Requirements Analysis for the
Enhanced Visual Approach Application

Version 1.2
16 April 2003

0.0 Operational Event Diagram

Figure 1 shows an operational event diagram for this application. Nodes (text boxes) represent events that involve either receipt of information by the crew or actions taken by the crew. The arcs (arrows) represent the possible transitions among these events. The crew receives information from multiple sources, including cockpit instruments (such as the ASA CDTI), direct sensing of the environment (for example by sighting another aircraft), and communications from other crews or from air traffic controllers. Crew actions include aircraft maneuvers, communications to other crews or to air traffic controllers, and entering data or setting adjustments on cockpit instruments.

Start and End nodes are shown for clarity. They are not associated with operational hazards and so are shown using rectangles with rounded corners to distinguish them from the events involved in the procedure itself.

1.0 Operational Safety Assessment

1.1 Operational Hazard Identification

The operational hazards for the Enhanced Visual Approach procedure are identified in Table 2. Operational hazards are identified semi-mechanically from the Operational Event Diagram in Figure 1 by assessing the implications of: (a) an operational event failing to take place when appropriate, which may mean it does not take place at all or that it is delayed, or, (b) an event occurring erroneously. The latter may mean either that the event occurs when not appropriate, or that the crew receives incorrect information, or that the crew takes an incorrect action.

Failures and errors related to informational events (events where the crew receives information from instruments, communications, or the environment) often do not have direct safety consequences, but rather may eventually result in the crew failing to act or acting incorrectly. In those cases, the safety consequence is shown as being one or more other operational hazards to which the informational operational hazard contributes rather than the ultimate potential safety consequences. In principle, one might consider only the crew actions as the source of operational hazards, and ignore the informational events. However, this would give little insight into how the ASA system might affect those operational hazards, as all of its effects are through informational events.

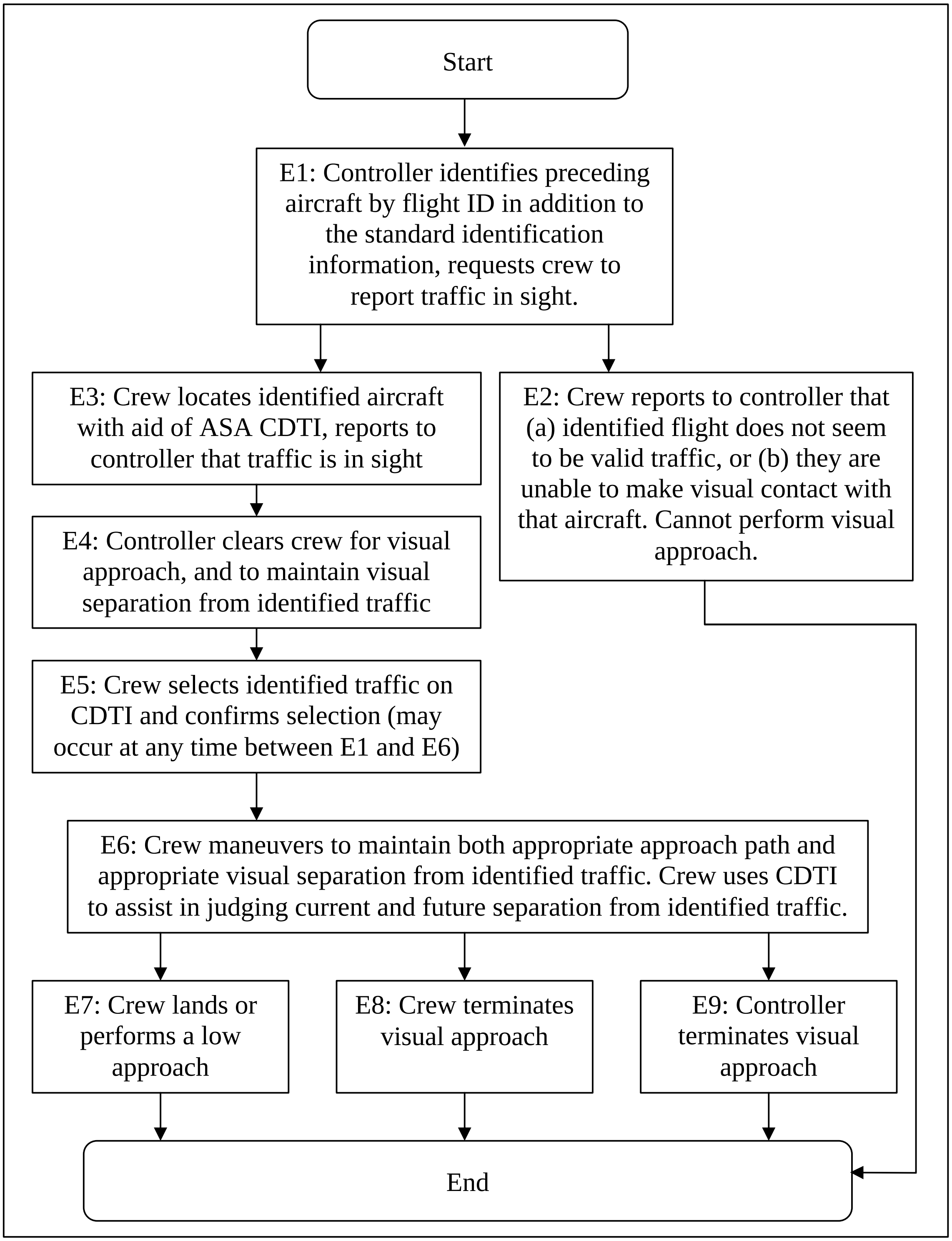

Figure 1: Operational Event Diagram for Enhanced Visual Approach

As shown in Table 2, each event in the Operational Event Diagram can be associated with a number of Operational Hazards, each of which then contributes to one or more worst-case Safety/Operational Consequence(s). For most of the operational hazards, there is either no safety/operational consequence or a minor consequence. The exceptions are as follows:

OH 1.4 Controller gives, or crews hears, an incorrect flight ID, but one that is at a plausible location on the approach.
(may contribute to 3.2, 5.3)

OH 3.2 Erroneous visual contact due to use of CDTI.
(may contribute to 6.2)

OH 5.3 Erroneous selection of traffic on CDTI.
(may contribute to 6.2)

OH 6.1 Crew follows correct aircraft but with incorrect maneuvers.
(may lead to wake vortex upset)

OH 6.2 Crew follows wrong aircraft.
(may lead to collision or wake vortex upset)

These operational hazards appear in the fault tree analysis in Section 1.3.1.

1.2 CDTI Failure Modes and Effects Analysis

In order to assess the contributory EVAppr failures and errors that could lead to the operational hazards identified in Table 2, a Failure Modes and Effects Analysis (FMEA) is performed for the EVAppr interface with the crew. This is a bottom-up analysis that identifies the component features of the CDTI interface for the EVAppr application and determines what operational hazards will result from failures or errors in each of these features. The results are presented in Table 3.

The required and optional features of the CDTI for the Enhanced Visual Approach application are listed in Table 4 of DO-259. However, some of these features provide multiple items of information to the crew. For example, the traffic symbol indicates the presence of traffic and also provides the range and bearing of that traffic. Therefore the CDTI features in Table 4 of DO-259 have been used to identify the different items of information provided to the crew. For each such information item the potential associated failures or errors are (a) the information is not received by the crew when appropriate, which may mean that it is not provided or that the crew does not pay attention to it, (b) the information is provided when it is not appropriate, and, (c) the information content is incorrect, which may mean that incorrect information is provided, or that the crew misreads or misunderstands the information. These are then related to the operational hazards identified in Table 2 that might result from that ASA CDTI failure or error. This also provides a crosscheck of the operational event diagram and the operational hazards identified from it. Each EVAppr interface failure or error should only result in safety consequences that are traceable through one of the identified operational hazards.

Crew input features of the CDTI have a slightly different list of generic failure modes. There is one crew input feature required for the Enhanced Visual Approach application, the ability to select a single aircraft of interest on the CDTI in order to receive additional information about that aircraft. For crew inputs, the generic failure modes are: (a) the crew fails to make the entry when appropriate, either not making it at all or doing it too late, (b) the crew makes the entry when it is not appropriate, or (c) erroneous data is entered. Equipment failures that have the same effect as crew errors must also be considered. The corresponding equipment failures are: (a) the equipment fails to respond to the crew's entry, (b) the equipment spontaneously acts as if the crew had made an entry, and (c) the equipment receives the data incorrectly even though it is entered correctly.

1.3 Fault Tree Analysis

The following analysis estimates the probability of accidents that might be caused by the use of the EVAppr procedure. Separate fault trees are presented for a collision and for a wake vortex upset, although the two analyses are similar. Since the basic visual approach procedure on which EVAppr is based is a standard safe procedure, the top-level events analyzed are collisions and wake vortex upsets induced due to the use of EVAppr. The probability of collisions and upsets inherent in the standard visual approach procedure is not analyzed. Figure 2 is the top-level fault tree for a collision caused by the use of EVAppr, while Figure 6 is a similar top-level fault tree for a wake vortex upset.

The metric used is the probability that a given event will occur during the approach operation. Events where the probability of occurrence cannot be controlled by setting requirements on the ASA system are shown with estimated probabilities, indicated by the word "ESTIMATED" on the event symbol (e.g., Figure 3, event C5). Events where the probability of occurrence can be controlled by setting requirements on the ASA system are shown as required probabilities, indicated by the word "REQUIREMENT" on the event symbol (e.g., Figure 3, event C10). The ASA system and the EVAppr application running on that system must be designed so that the probability of that event is less than or equal to the given probability in order to meet the overall safety targets. For non-leaf events, a calculated value is shown, computed from the estimated and required probabilities of all the leaf events of their subtree. [*Note: estimates are given to the nearest power of ten.*] The top-level accident events are required to have a probability less than or equal to the target level of safety for those events. For a collision the safety target is a probability of 10^{-9} or less per operation, and for a wake vortex upset the safety target is a probability of 10^{-7} or less per operation.

1.3.1 Collision Fault Tree Analysis

Figure 2 is the top-level fault tree for a collision caused by the use of EVAppr. Fault trees are related to the Operational Hazard Analysis (OHA, Table 2) and the Failure Modes and Effects Analysis (FEMA, Table 3) as follows. The FEMA enumerates possible problems with the required CDTI information (e.g., missing or erroneous information) and indicates the operational hazards to which each problem could contribute. Operational hazards that could lead to a safety problem appear in the fault trees. Labels OH n.n attached to symbols in the fault tree refer to the operational hazards as defined in Table 2.

As noted in Figure 2, event C1 ("The use of EVAppr induces a collision with the aircraft that the crew is following") is not considered to be a credible event. In order for EVAppr to be initiated, the crew must have visually located the identified traffic. As long as visual contact is maintained (a requirement in order for the application to continue), it is assumed that the crew will avoid a collision with the traffic. [For example, if the CDTI displays incorrect distance information, either the distance error is small enough to be undetectable by the crew (in which case, the error would not lead to a collision), or the distance error is large enough to be detected by the crew (in which case the crew will recognize that the CDTI is in error and disregard the information, again not leading to a collision)].

If visual contact is lost, in order for a collision to occur, the CDTI would have to display incorrect information and the crew would have to use this information long enough for the separation to be lost, an extreme violation of the operational procedure.

Thus, C1 is not considered to be a credible event, the required rate of occurrence is met by assumption, and event C1 is not expanded further. Figures 3 and 4 expand the subevents C3 and C4 identified in Figure 2.

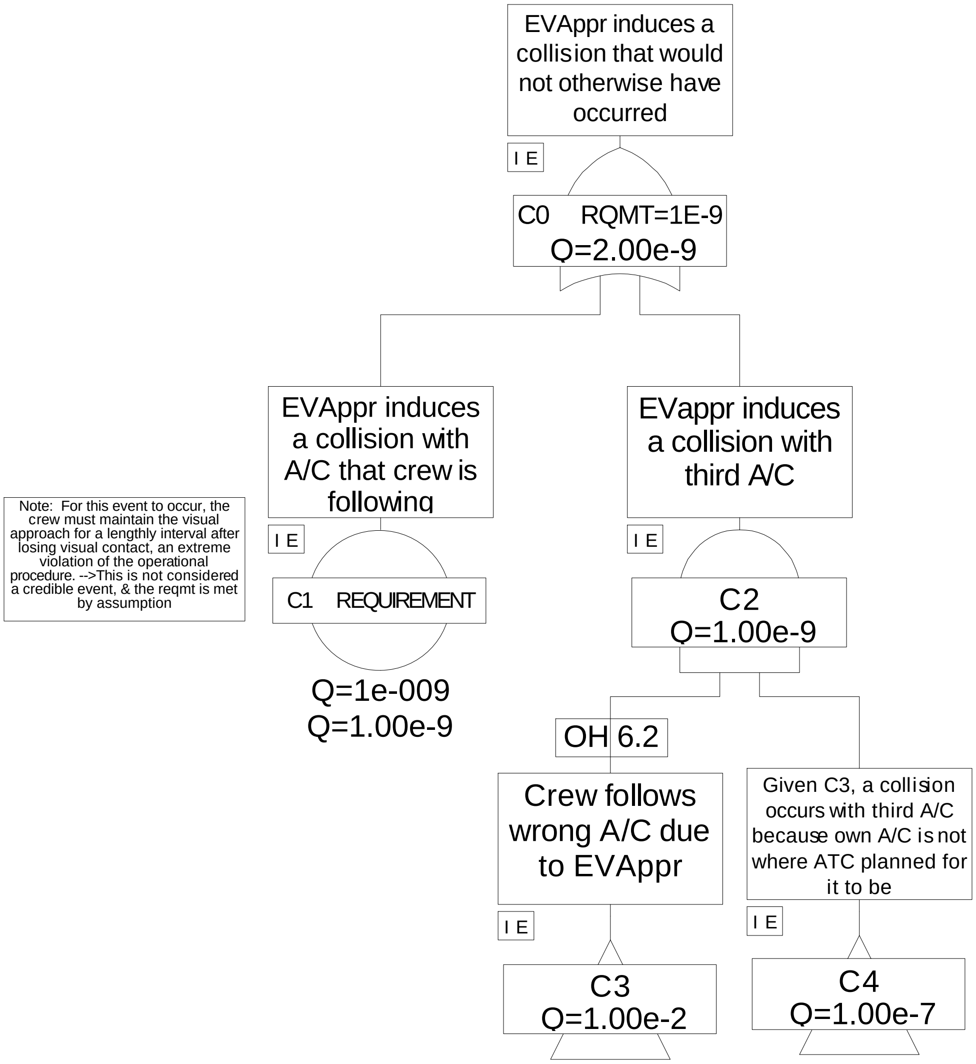

Figure 2. Top-level Fault Tree - Collision

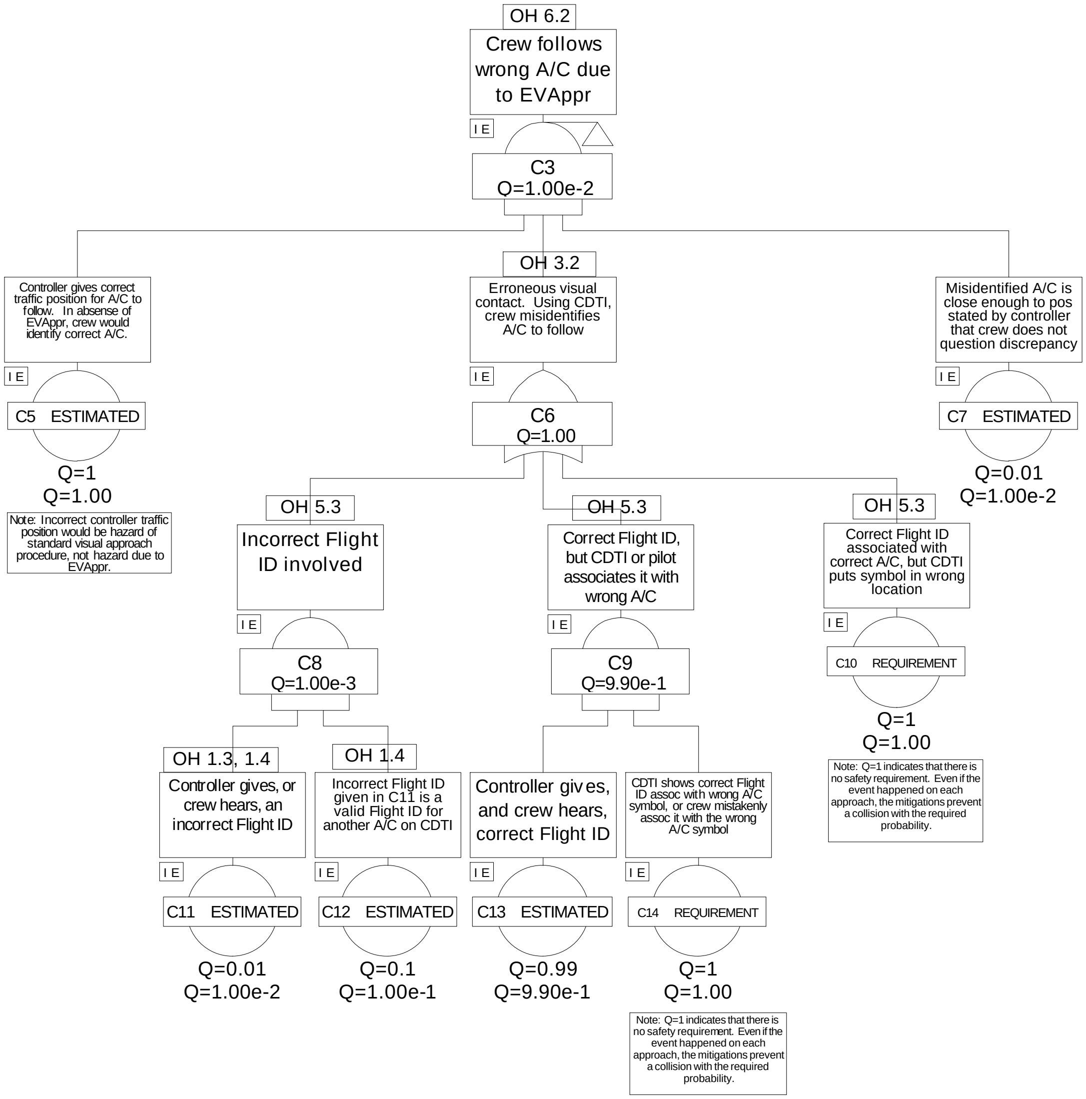

Figure 3. Expansion of Event C3

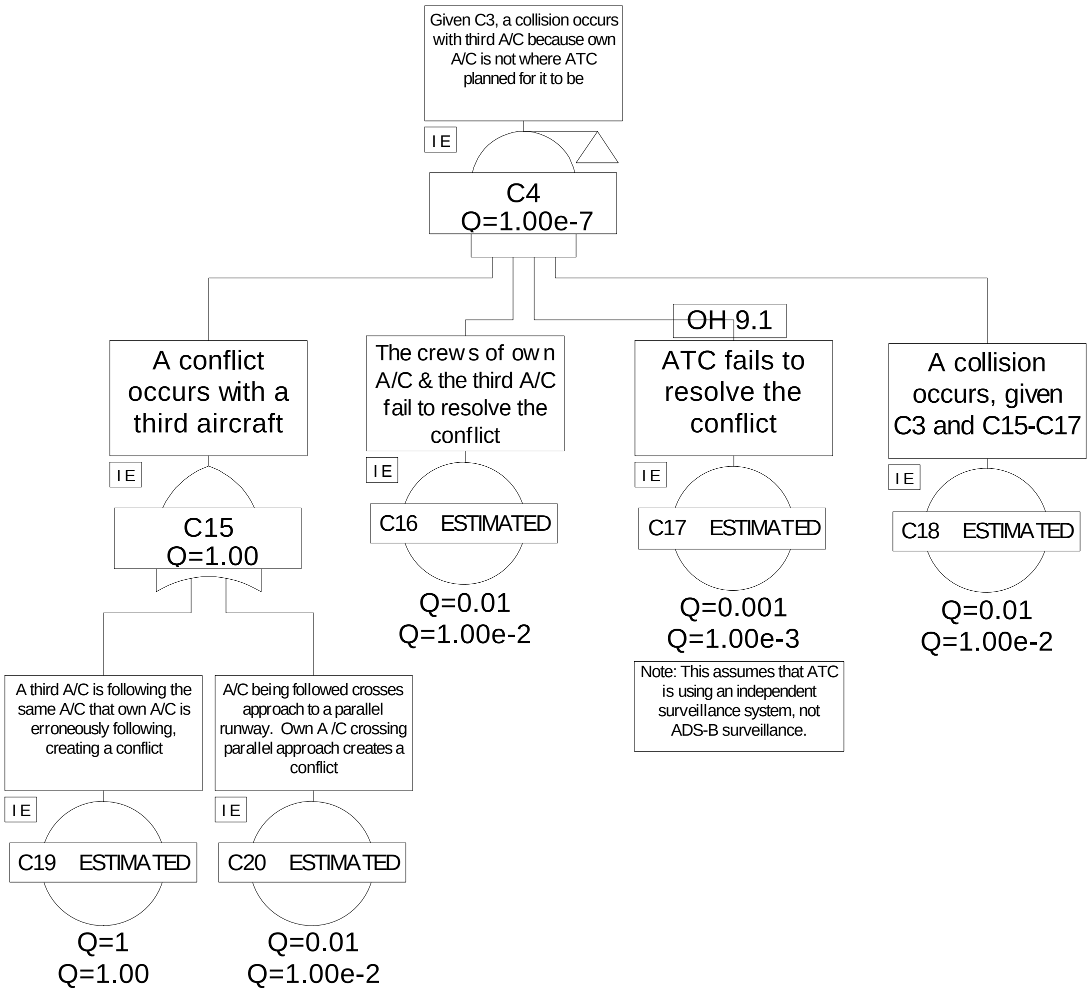

Figure 4. Expansion of Event C4

1.3.2 Wake Vortex Upset Fault Tree Analysis

Figure 5 shows the top-level fault tree for a wake vortex upset. The analysis is similar to that for a collision. Individual events from the collision analysis have been used without modification. Events unique to the wake vortex analysis are labeled Wn where n is an integer. Events labeled Cn refer to events in the collision fault tree.

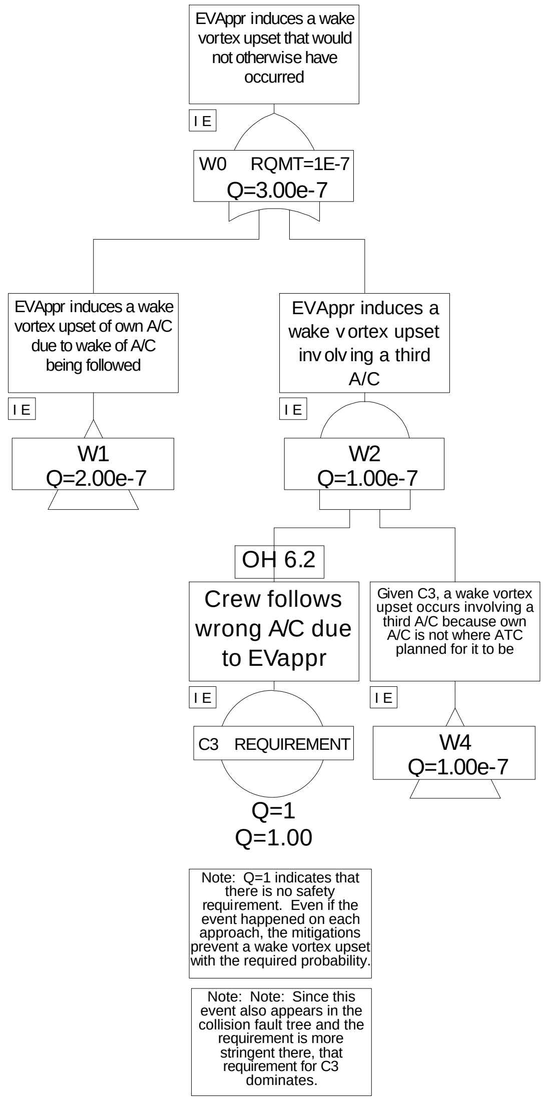

Figure 5. Top-level Fault Tree – Wake Vortex Upset

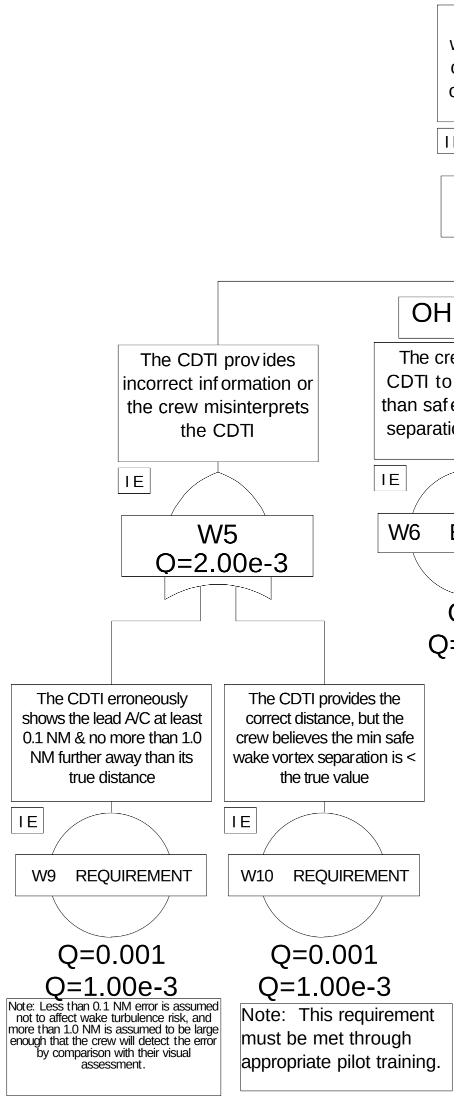

Figure 6. Expansion of Event W1

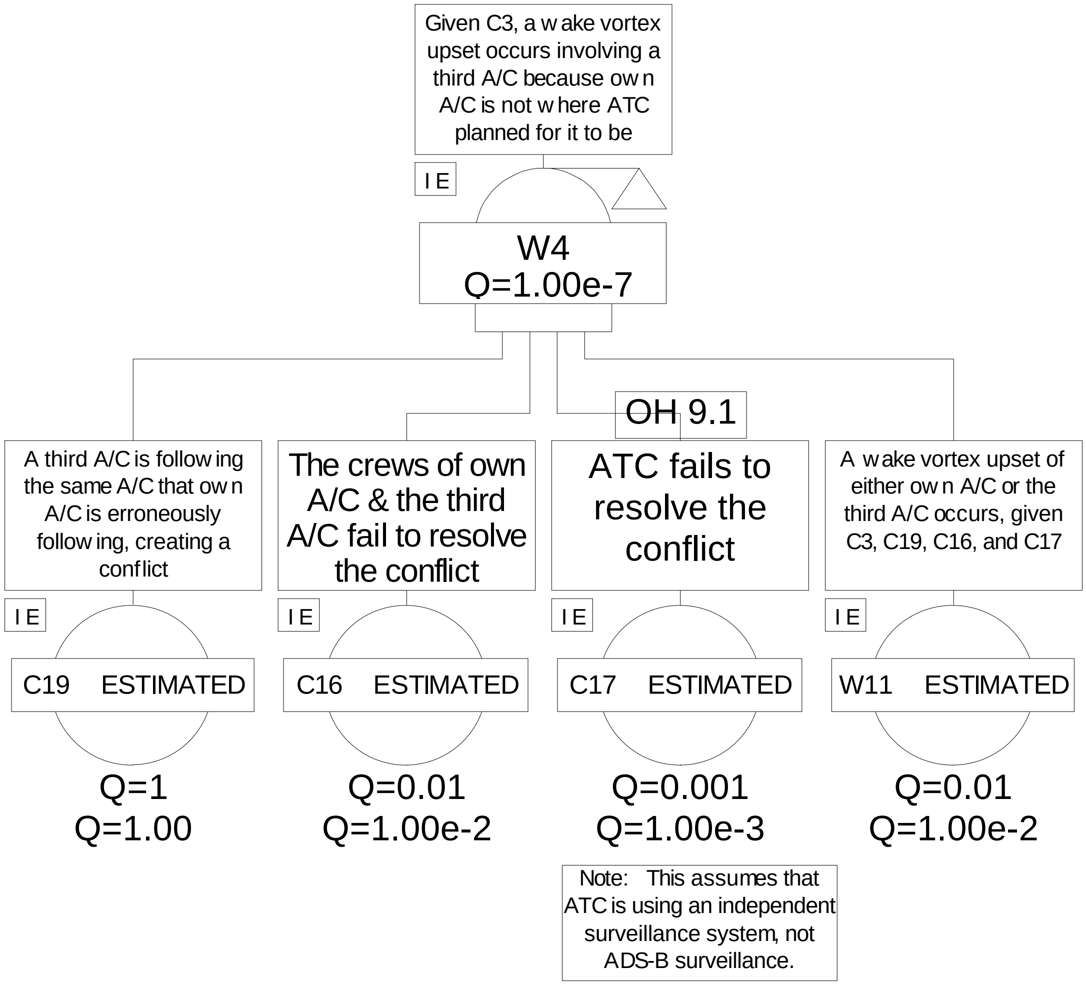

Figure 7. Expansion of Event W4

1.3.3 Discussion

Safety considerations place no requirements on the availability or continuity of the EVAppr application. The EVAppr procedure is an enhancement to the standard visual approach procedure, which in turn is an enhancement of standard instrument approach procedures. Any failure of the EVAppr capabilities that is noticed by the crew results in falling back on the standard visual approach or instrument approach procedures. These existing procedures are considered safe and completely mitigate any detected failure of the EVAppr application, as long as the EVAppr procedure and the ASA system that supports it do not interfere with the operation of these standard procedures in some fashion.

An assessment was made of the possibility that the EVAppr application might interfere with the normal visual approach procedure by interfering with operational procedures and communications that support the normal visual approach or instrument approach procedures. The performance of the standard visual approach procedure depends on ATC radio communications to initiate the procedure and to identify the traffic to the crew. It also depends on ATC radio communications for termination of the procedure by either the crew or the controller. Once the traffic is identified and clearance for the visual approach is given, the procedure depends on the crew maintaining visual contact with the traffic identified by the controller. The EVAppr application does not use audio alerts or advisories, and so cannot interfere with ATC radio communications. Although the crew must occasionally check the CDTI during the EVAppr procedure, the small amount of time required should not interfere in any way with the crew's ability to maintain visual contact with the identified traffic, and in fact may enhance that ability. Overall, the conclusion is that the EVAppr application will not interfere with the standard visual approach procedure.

The fault tree analysis above indicates that most erroneous information and crew actions arising from the use of the EVAppr procedure are mitigated completely by other existing procedures, except for the possibility that errors in the displayed distance to the lead aircraft or crew misinformation may lead to a wake vortex upset of own aircraft due to the wake of the aircraft being followed. The potential forms of error are identified through the identification of operational hazards in Table 2 and the CDTI FMEA in Table 3. Two general areas of concern are identified. First there is the possibility that the crew might incorrectly identify the aircraft to follow, resulting in a collision or a wake vortex upset involving a third aircraft. Errors of this sort appear to be completely mitigated, as seen in the fault tree analysis. Second, there are the possibilities that the CDTI may display an incorrect distance to the lead aircraft, or that the crew may have an incorrect understanding of the safe wake vortex separation, leading to a wake vortex upset due to loss of appropriate separation from the aircraft they are following.

The net result of this Operational Safety Analysis is that there is a requirement for a bound on the error in the distance shown to the lead aircraft and for the actual error not to exceed this bound more often than once in every 1000 approaches. In addition, training procedures for EVAppr should emphasize the safe minimum wake vortex separation distances for crews to use as their target separation distances from various categories of aircraft, and should provide rules for termination of a visual approach when visual contact is lost.

2.0 Operational Performance Assessment

The Enhanced Visual Approach application is comprised of two distinct processes: 1) the initial visual acquisition of the target aircraft that is to be followed, and 2) the positioning and station-keeping of own aircraft to maintain appropriate separation during the visual approach.

2.1 Initial Visual Acquisition

The initial visual acquisition of the target aircraft will impose requirements at least as stringent as those for the Enhanced Visual Acquisition application. An additional consideration is that the Enhanced Visual Approach application requires that the crew or pilot identify a particular target from among several aircraft being positioned for an approach in a potentially crowded airspace. The target aircraft, or even the nearest aircraft, may not be a collision threat. This application requires that the pilot or crew match the traffic picture on the CDTI with the visual traffic picture, potentially more challenging than the visual acquisition of a single target.

A representative challenging traffic picture for this application is depicted in Figure 9. Own aircraft is downwind and must visually merge into one of two streams of traffic flowing to two runways. Minimum separation on final approach in instrument conditions is normally 3.0 NM. At airports with demonstrated average runway occupancy times of less than one minute, this can be reduced to 2.5 NM. There is no specific separation requirement when conducting visual approaches, but considering runway occupancy times, average in-trail separation for visual approaches is not less than about 2.0 NM. (120 knots approach speed and 1-minute runway occupancy time imply that the trailing aircraft should be 2 NM out when the lead aircraft lands.)

Aircraft being vectored onto the final approach will normally be separated so as to allow for a compression effect as the aircraft slow down to final approach speed. En-route separation is 5 NM and the separation limit at landing was shown above to be 2 NM. Thus, a typical separation distance for aircraft being vectored in visual conditions would be 3.0 - 4.0 NM. Therefore, in the traffic scenario depicted in Figure 9, reasonable in-trail separations for traffic conducting visual approaches would be 2.0 NM on final and 3.0 – 4.0 NM in the arrival stream when being vectored to final.

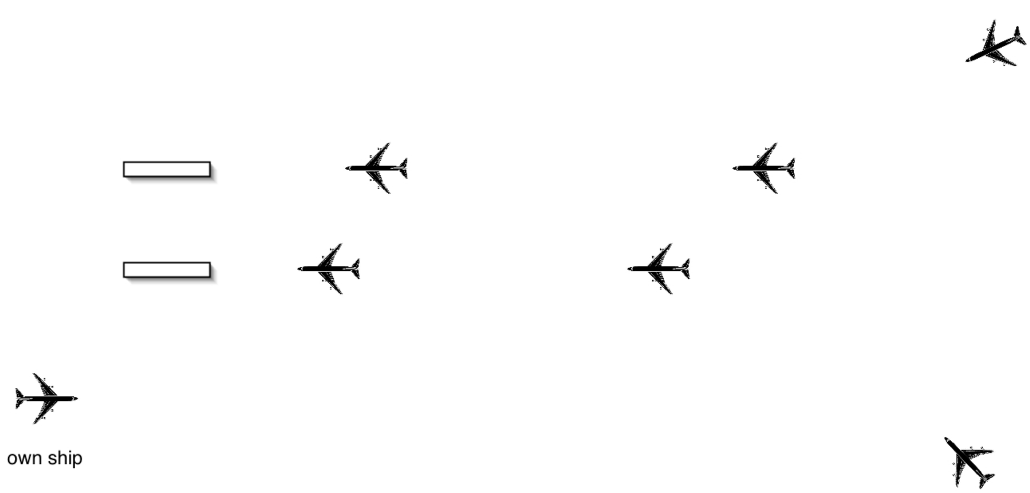

Figure 9: A representative challenging traffic picture for the acquisition phase of the Enhanced Visual Approach application

Based on representation of approach traffic pictures on a TCAS display, it is estimated that in order for the pilot or crew to be able to reliably determine the traffic pattern from the CDTI and match it to the traffic seen visually, the positional errors contributing to the displayed separation of a stream of traffic should not cause more than an approximately10% to 20% error in the displayed separation between two aircraft. If the positional errors were so large that the separation distances in the traffic flow were more than 10% or 20% in error, it would be difficult for the pilot or crew to maintain a situational awareness of the traffic flow and visually distinguish individual aircraft based on the CDTI depiction of the traffic.

Using the 2.0 NM minimum separation and allocating the errors between aircraft on a worst case basis, the individual aircraft positional errors should not be more than 5% - 10% of the separation of 2.0 NM in order to limit the displayed separation error to 10% - 20% of the 2.0 NM separation. This suggests a positional navigation error of not more than 0.1 – 0.2 NM. If the positional errors are allocated between individual aircraft in a root mean square manner, then a positional error limit of approximately 0.14 – 0.28 NM is required to keep the separation error within 10% - 20% for a 2.0 NM separation.

Another consideration which can be seen in Figure 10 is that the pilot or crew is likely to be required to select visually between targets that are close in bearing but differ in range. It is very difficult to determine range visually, so for this application it becomes important that the CDTI not display misleading information of the traffic situation through errors in bearing; that is, the relative bearings of two targets seen visually should match what is displayed on the CDTI.

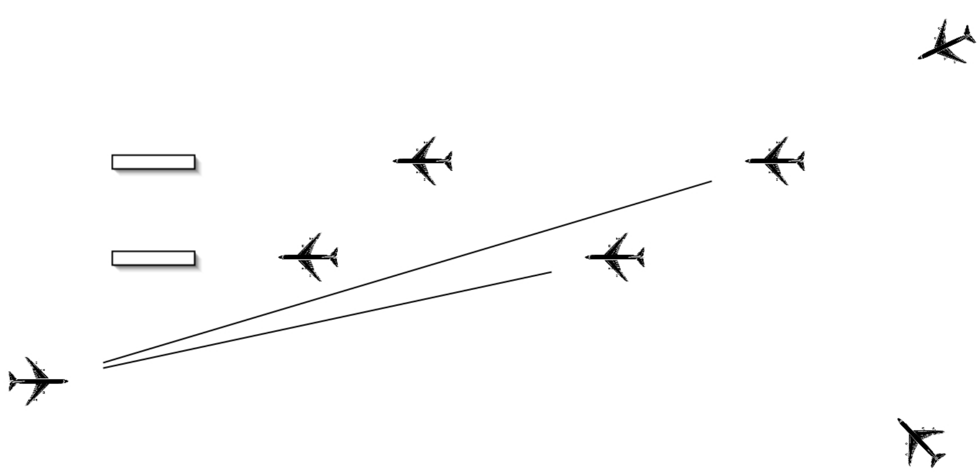

Figure 10: Illustration of aircraft at different ranges but similar bearings that may have to be distinguished in the Enhanced Visual Approach application

RTCA DO-239, *Minimum Operational Performance Standards for Traffic Information Service (TIS) Data Link Communications*, specifies relative bearing information be quantized in 6 degree increments. This suggests a bearing error of no more than ± 3 degrees. At a range of 2 NM, a typical minimum distance at which visual acquisition must be accomplished, a horizontal position error of 0.1 NM will result in a relative bearing error of approximately 3 degrees. At a range of 5 NM, a typical maximum distance for visual acquisition, a horizontal position error of 0.26 NM will result in a relative bearing error of approximately 3 degrees.

A mitigating consideration is that the pilot or crew will have some time to achieve situational awareness of the traffic and to visually acquire a specific target aircraft based on the ID displayed on the CDTI. Thus, the crew need not rely solely on a single display update, but can follow the movement of traffic over time to assist in identification. The controller is required by procedure to not clear the aircraft for a visual approach on the basis of the CDTI only. However, the controller can wait until a point in the approach when the pilot is most likely to have correctly identified the other aircraft.

RTCA DO-243, *Guidance for Initial Implementation of Cockpit Display of Traffic Information*, has requirements for various applications and suggests that a relative bearing accuracy of 3 degrees and a range accuracy of 0.1 NM (both rms) would be required to meet the needs of the Enhanced Visual Approach application.

NACp values defined by RTCA DO-260 (ADS-B MASPS) include 0.1 NM and 0.3 NM. The operational considerations described above suggest that a desired target level for positional accuracy should be 0.1 NM and that 0.3 NM be considered a minimum requirement.

This type of visual application, which is an enhancement of a currently accepted procedure, does not impose any integrity requirements on the data.

Additional requirements for the Enhanced Visual Acquisition application include a 10 NM range ± 3500 feet altitude detection volume, and the capability to display at least 10 aircraft on the CDTI. The traffic patterns in Figure 9 indicate that these numbers would be adequate for the Enhanced Visual Approach application. The outer marker for an approach is typically about 5 NM from the threshold, so a range of 10 NM would include all aircraft on the approach and those being vectored for the approach. If there were two streams of aircraft 2 NM in-trail, then there would be no more than 10 aircraft within the 10 NM range. The 10 NM range ± 3500 feet altitude detection volume would include all aircraft being vectored for the approach, including any target aircraft that would need to be acquired visually to conduct the application.

The maximum 3-second update rate specified for the Enhanced Visual Acquisition application may not be adequate for the more challenging visual acquisition phase of the Enhanced Visual Approach application because the pilot or crew must match the traffic picture on the CDTI with the visual traffic picture for traffic that is being vectored onto the final approach and pick out a specific target. The slowest traffic will be moving at least 120 knots and will cover the 0.1 NM positional accuracy requirement in 3 seconds. Traffic flying at 180 knots would cover that distance in 2 seconds. It seems that a 2 second update rate is desirable and a 3 second update rate a minimum requirement.

The maximum latency of six seconds specified for Enhanced Visual Acquisition for own and target aircraft may not be adequate for Enhanced Visual Approach under similar reasoning, i.e., due to the Enhanced Visual Approach's more challenging visual acquisition phase. However, latency in itself does not distort the aircraft positions relative to each other and to own aircraft; it is only a delay in the presentation. For this reason, a three second latency is desirable with a minimum requirement for no more than a six second latency.

Altitude information is primarily used to acquire the target aircraft. Even though the acquisition for this application may be under more trying traffic conditions, the altitude accuracy requirements for this phase of the application appear no different than those for the Enhanced Visual Acquisition application: specifically, a vertical position accuracy of 200 feet and a vertical integrity containment bound of 500 feet.

2.2 Positioning and Station-Keeping

The positioning and station-keeping phase of this application must support a pilot or crew attempt to maintain the appropriate spacing. The positional accuracy and update rate requirements would seem to be less stringent for this phase than for the initial visual acquisition phase of this application because the target aircraft has already been visually acquired and the relative position of the target aircraft is nearly constant. However, the requirements for navigational accuracy of reported velocity for the target and own ship will be more stringent than the 25 knots specified for the Enhanced Visual Acquisition application because in the Enhanced Visual Approach application it is expected that some benefit will be achieved by more accurate spacing on final approach, allowing potentially more throughput to the runway.

To support maintaining the appropriate spacing, the Enhanced Visual Approach application requires that the CDTI display the ground speed or the closure rate of an aircraft that the crew selects (presumably the target aircraft). These speed indications alert the pilot or crew when the preceding aircraft slows down, well before a significant reduction in range would be noticed visually. Airline category aircraft are required to fly a stabilized final approach. Once an aircraft is established on a stabilized final approach a change in ground speed of 25 knots would be unusually high. If the resolution for reporting ground speed were no better than 25 knots then this data would not be useful for improving spacing in this application. Therefore, the required accuracy would have to be small enough to measure changes in ground speed of a maximum of 25 knots.

A five-knot error would result in an error in the predicted range that would grow at the rate of 0.0833 NM per minute. Thus a crew intending to maintain a constant distance from the target aircraft and assuming a closure rate of zero would only notice a discrepancy of on the order of 0.1 NM, the desired positional accuracy, after a little more than a minute. This is the approximate inter-arrival time at the runway for visual approaches.

The allowed NACv values are specified in meters per second and include <10 m/s, < 3 m/s, and <1 m/s. 3 m/s corresponds to 5.8 knots and 1 m/s corresponds to 1.9 knots. This suggests that the requirement should be < 3 m/s.

The altitude and vertical velocity accuracy requirements do not seem to be any more stringent than those for the Enhanced Visual Acquisition application during the station-keeping phase of this application. During this phase of the Enhanced Visual Approach application, own aircraft is managing altitude based on the approach independent of the target aircraft. Once the target aircraft is acquired visually, the task is to maintain horizontal separation while each aircraft monitors its altitude based on the distance from the runway. The vertical position accuracy of 200 feet, vertical integrity containment bound of 500 feet, and vertical velocity accuracy of ± 20% specified in the Enhanced Visual Acquisition application seem adequate for the Enhanced Visual Approach application.

The other information elements for the Enhanced Visual Acquisition application are deemed to be adequate for the Enhanced Visual Approach application. These include a maximum target data coast time of 6 seconds, a target state data continuity and availability of 0.95, a target state data coverage of 10 NM, own ship latency of 6 seconds and own ship report time accuracy of ± 1 second.

Values for information elements in section 3.0 not specifically discussed above are identical to the values used for the Enhanced Visual Acquisition application.

[Editorial note: The values are from the Enhanced Visual Acquisition application table provided by Lee Etnyre as of January 2003. These should be confirmed against the final values.]

3.0 Requirements Summary

This section summarizes the requirements that have been derived in the sections above. The fault tree analysis in the Operational Safety Assessment indicates that errors in the displayed distance to the lead aircraft or crew misinformation may lead to a wake vortex upset of own aircraft due to the wake of the aircraft being followed. This leads to a requirement for a bound on the error in the distance shown to the lead aircraft and for the actual error not to exceed this bound more often than once in every 1000 approaches.

All other requirements come from the Operational Performance Assessment. Here, the requirements for the Enhanced Visual Approach application are the same as those for Enhanced Visual Acquisition with two exceptions: more stringent positional accuracy is needed to visually distinguish a target in a challenging terminal traffic flow picture, and increased accuracy is needed for the ground speed reporting in order to maintain accurate spacing during the approach.

Table 1: Information Elements

Information Category	Information Quality	
Target State Data – Accuracy	Navigation accuracy – position (NACp)	Desired 0.1 NM Minimum 0.3 NM
	Navigation accuracy category -- velocity (NACv)	< 3 m/s
	Heading Accuracy (95%)	N/A
Target State Data – Integrity	Surveillance Integrity Level (SIL)	≥ 1 (≤ 1 x 10^{-3})
	Navigation Integrity Category (NIC)	0.1 NM
	Maximum Delay to indicate integrity (NIC) change	
Target State Data – Timing Parameters	Effective Update Rate (moving vehicles)	3 sec
	Effective Update Rate (non-moving vehicles)	3 sec
	Report Time Accuracy (95%)	± 1 sec
	Latency *ed note: need to allocate among subsystems, esp. ads-b xmit & receive in chapter 3*	6 sec
	Maximum coast time (moving vehicles)	6 sec
	Maximum coast time (stationary vehicles)	6 sec
Target State Data – Other Parameters	Data Continuity	0.95
	Data Availability	0.95
	Coverage	10 NM ± 3500 ft
Own ship state data	Horizontal position Accuracy	Desired 0.1 NM Minimum 0.3 NM
	Horizontal velocity accuracy	< 3 m/s
	Vertical position accuracy	200 ft
	Vertical velocity accuracy	± 20%
	Horizontal Integrity containment radius, Rc	0.1 NM
	Vertical integrity containment bound	500 ft
	Navigation Integrity Level	≤ 1 x 10^{-3}
	Latency	6 sec
	Report time accuracy	± 1 sec

Alternative Approach to NIC Requirement

Note: There appear to be two ways to address the requirement on distance error shown in fault tree event W9. One way was presented in the text in Section 1.3.3, i.e., to disallow the EVAppr procedure unless strict bounds on the distance error could be established. The second way, dscribed below, would require a minor change to the EVAppr operational concept in exchange for potentially wider applicability of the EVAppr procedure.

Since the ADS-B position reports contain information that bounds the position uncertainty (via the NAC and NIC/SIL parameters), and since own aircraft has information that similarly bounds its own position uncertainty, the problem of erroneous distance measurements could be addressed by informing the crew of the potential distance error whenever that value exceeds some tolerance, such as 0.1 NM. The fault tree analysis (event W9) indicates a requirement that the uncertainty bound should be calculated such that the distance error will not persistently exceed the displayed bound more frequently than 1 approach in 1000. (Transient distance errors could be filtered out by the EVAppr application, or simply ignored by the crew.) This could be achieved by requiring a SIL of 1 or greater ($=10^{-3}$ per flight hour, or per operation) from both the lead aircraft and own aircraft, and summing the associated NIC values to obtain a distance uncertainty bound. The crew would then simply add that distance uncertainty bound to the appropriate wake vortex separation value for that approach and use that as the target separation distance. If the potential error was very large, they could choose not to use the CDTI to judge separation. However, this use of the reported distance uncertainty bound by the crew is a variation on the operational procedure currently defined for Enhanced Visual Approach.

Table 2: Identification of Operational Hazards for Enhanced Visual Approach

Event	Operational Hazard ID	Operational Hazard Description	Worst-case Safety Consequence
E1: Controller provides traffic information	OH 1.1	Controller fails to provide traffic information, or delays providing traffic information. Unable to use procedure, or delay in initiating procedure. Potentially loss of some efficiency benefits.	None.
	OH 1.2	Controller erroneously determines that equipage is appropriate to use Enhanced Visual Approach: -- Preceding traffic not being shown on own aircraft's CDTI -- Own aircraft not equipped with ASA CDTI Crew will communicate condition to controller in event E2. Standard visual approach will be used.	Minor workload.
	OH 1.3	Controller provides erroneous information on preceding traffic, or crew misunderstands identification: -- Flight ID of non-existent flight or one not at plausible location on the approach Crew will report traffic not shown on CDTI, or question identification in event E2.	Crew workload.
	OH 1.4	Controller provides erroneous information on preceding traffic, or crew misunderstands identification: -- Flight ID of the wrong flight, but one that is at plausible location on the approach	Contributes to OH 3.2, 5.3
E2: Crew reports unable to perform EVAppr.	OH 2.1	Failure to notify controller, or delay in notifying controller. No safety consequence. Delay in switching to alternative procedures. Potential loss of efficiency benefits.	None.
	OH 2.2	Error in notifying controller. Crew erroneously indicates cannot perform EVAppr. No safety consequence. Switch to standard visual approach procedure. Loss of any EVAppr safety or efficiency benefits.	None.
E3: Crew reports traffic in sight	OH 3.1	Failure to establish or report visual contact, or delay in establishing or reporting visual contact. No safety consequence. Unable to continue procedure, or delay in continuing procedure. Loss of any efficiency benefits.	None.
	OH 3.2	Erroneous visual contact. -- Controller identifies wrong aircraft to crew, or crew misunderstands identification, and crew makes visual contact with that aircraft. -- Crew identifies wrong aircraft as the traffic called by controller.	Contributes to OH 6.2

Event	Operational Hazard ID	Operational Hazard Description	Worst-case Safety Consequence
E4: Clearance for visual approach	OH 4.1	Failure to receive clearance or delay in receiving clearance. No safety consequence. Unable to continue procedure, or delay in continuing procedure. Loss of efficiency benefits.	None.
	OH 4.2	Erroneous clearance. Crew has not indicated visual contact with traffic, or meteorological conditions inappropriate for visual approach. Crew may question clearance if appears inappropriate. If accepts clearance, crew or controller will cancel visual approach if conditions inappropriate.	Minor workload.
E5: Crew selects identified traffic on CDTI	OH 5.1	Failure to select identified traffic on the CDTI. Crew does not benefit from additional information provided on selected traffic. Crew may have difficulty repeatedly finding identified traffic on the display in dense traffic.	Minor crew workload.
	OH 5.2	Erroneous selection of identified traffic on CDTI, when crew correctly understands which traffic the controller intends. Crew will most probably recognize error, as the highlighted traffic on the CDTI will have the wrong flight ID, and will redo selection.	Minor crew workload.
	OH 5.3	Erroneous selection of identified traffic on CDTI, due to crew incorrectly understanding which traffic the controller intends.	Contributes to OH 3.2, 6.2
E6: Crew maneuvers to maintain approach path and visual separation	OH 6.1	Failure to maneuver when appropriate, or delay in maneuvering, or erroneous maneuvers. Crew follows correct aircraft	Wake vortex upset with aircraft being followed.
	OH 6.2	Failure to maneuver when appropriate, or delay in maneuvering, or erroneous maneuvers. Crew follows wrong aircraft.	Wake vortex upset with aircraft being followed or another aircraft. Collision with other traffic.
E7: Crew lands or makes low approach	--	Failure to finish the approach implies termination of the visual approach, so that either E8 or E9 occur instead.	--
	OH 7.1	Crew cannot land due to preceding traffic still on the runway. Loss of any efficiency benefits.	Controller workload.
E8: Crew terminates visual approach	OH 8.1	Failure to terminate visual approach when appropriate, or delay in terminating visual approach.	Contributes to OH 6.1, 6.2, 7.1

Event	Operational Hazard ID	Operational Hazard Description	Worst-case Safety Consequence
	OH 8.2	Erroneous termination of visual approach. Visual approach terminated although conditions continue to be appropriate for a visual approach. Aircraft may not have appropriate IFR separation at termination of visual separation. May lead to go-around. Potential loss of any efficiency benefits.	Controller workload.
E9: Controller terminates visual approach	OH 9.1	Failure to terminate visual approach when appropriate, or delay in terminating visual approach.	Contributes to OH 6.1, 6.2, 7.1
	OH 9.2	Erroneous termination of visual approach. Visual approach terminated although conditions continue to be appropriate for a visual approach. Aircraft may not have appropriate IFR separation at termination of visual separation. May lead to go-around. Potential loss of any efficiency benefits.	Controller workload.

Table 3: CDTI Failure Modes and Effects Analysis

Required Information	**Failure Mode**	**Effect**	**Contributes to Operational Hazard(s) (see table 2)**
Traffic presence (traffic symbol)	Fails to display when appropriate.	For traffic other than the traffic called by the controller, may delay visual acquisition of the called traffic if the crew has trouble matching the aircraft seen out the window with the traffic pattern on the CDTI (OH 3.1). This would also be the case if there were unequipped traffic in the pattern. For the traffic called by the controller, if the crew is not yet cleared for the EVAppr, and the crew cannot identify the traffic visually, they will follow event E2, terminating the EVAppr. There is no operational hazard in that case. If the crew is already performing the EVAppr and the traffic symbol disappears, that eliminates the crew's ability to use the CDTI as an aid to maintaining visual contact and as an aid to judging current and projected separation. In both cases, they fall back to standard visual approach procedures.	OH 3.1
	Traffic indicated when not appropriate. False traffic indication, or indication of traffic that is not of concern.	May lead to some delay in identifying traffic called by the controller (OH 3.1)	OH 3.1
	Erroneous information content.	Not applicable as this information item indicates presence/absence only.	N/A
Traffic altitude or relative altitude	Fails to display when appropriate. A traffic symbol is shown, but traffic altitude or relative altitude is not shown.	May delay crew visual acquisition (OH 3.1). When this affects the traffic called by the controller, the crew will not be able to use the CDTI as an aid in assessing altitude separation. However, this is unlikely to affect crew actions, as visual assessment of relative altitude as in a normal visual approach is adequate.	OH 3.1

Required Information	Failure Mode	Effect	Contributes to Operational Hazard(s) (see table 2)
	Displays when not appropriate.	Altitude should always be displayed whenever a traffic symbol is displayed. Display of altitude information without an associated traffic symbol would be an equipment failure that is obvious to the crew.	None
	Erroneous information content. Incorrect altitude information is displayed for one or more targets on the CDTI, or the crew misunderstands the altitude information.	May delay crew visual acquisition of the called traffic (OH 3.1). If the traffic seen out the window matches the pattern on the CDTI except for the altitudes, may lead crew to query the controller and to question whether the CDTI is functioning correctly. When it affects the traffic called by the controller after the visual approach clearance has been given, it is unlikely to contribute to any operational hazards. If the error is small, it will not be noticed and will not affect safety. If it is large it will conflict with the crew’s visual assessment of relative altitude and lead to the crew questioning the altitude shown on the CDTI.	OH 3.1
Traffic bearing	Fails to display when appropriate.	Bearing should always be provided whenever the presence of traffic is indicated. But, relative bearing is judged from the relative positions of own aircraft symbol and the traffic symbol used to show the presence of traffic. Failure to display relative bearing when traffic is present implies that own aircraft symbol is missing, an obvious equipment failure.	None
	Displays when not appropriate.	Meaningless, as relative bearing should be displayed whenever traffic is present, and is indicated using the same symbol used to indicate the presence of traffic.	N/A
	Erroneous information content. The traffic symbol for one or more aircraft is displayed with a relative bearing error that is significantly different from that of other traffic near to it, or the crew misunderstands the bearing information.	The crew may have difficulty matching the traffic seen out the window with the CDTI picture, and so have difficulty in identifying the called traffic (OH 3.1). The crew may mis-identify the called traffic (OH 3.2). Bearing is not used in this procedure to judge separation from the called traffic, so events E6, E7 and E8 are not affected	OH 3.1 OH 3.2

Required Information	Failure Mode	Effect	Contributes to Operational Hazard(s) (see table 2)
	Erroneous information content. The traffic symbols for all traffic are displayed with approximately the same error in relative bearing, that is, the relative bearing of all traffic shown on the CDTI display is rotated from the true relative bearing. This might be due, for example, to failure or inability to correct for the crab angle of the aircraft in high crosswinds.	The crew can adjust for this if the erroneous rotation is not too great and they can match the traffic pattern seen out the window with the pattern shown on the CDTI. Otherwise, the crew may have difficulty identifying the called traffic (OH 3.1), and may mis-identify the called traffic (OH 3.2). Bearing is not used in this procedure to judge separation from the called traffic, so events E6, E7 and E8 are not affected.	OH 3.1 OH 3.2
Traffic range	Fails to display when appropriate. Range should always be provided whenever the presence of traffic is indicated.	Range is judged from the distance between own aircraft symbol and the traffic symbol used to show the presence of traffic. Failure to display range when the traffic symbol is present can only happen if own aircraft symbol and the range reference are missing, an obvious equipment failure. If the range of the selected traffic is provided in a text field in addition to its ground speed or closure rate, then the failure to display this information is also an obvious equipment failure. The additional information is not available to the crew for judging future separation, and the crew must rely on visual observation alone as in a standard visual approach, possibly aided by the less accurate range estimate that they can obtain from the traffic symbol for the selected target.	None
	Displays when not appropriate.	Meaningless, as range should be displayed whenever traffic is present, and is indicated using the same symbol used to indicate the presence of traffic.	N/A

Required Information	**Failure Mode**	**Effect**	**Contributes to Operational Hazard(s) (see table 2)**
	Erroneous information content. The traffic symbol for one or more aircraft is displayed at the wrong range, or the crew misunderstands the range information.	The crew may have difficulty matching the traffic seen out the window with the CDTI picture, and so have difficulty in identifying the called traffic (OH 3.1). The crew may mis-identify the called traffic (OH 3.2). If it affects the traffic called by the controller, it may cause the crew to misjudge the current or projected horizontal separation. If the separation shown is smaller than the actual separation, it may lead to unnecessarily large separation or unnecessary termination of the procedure (OH 8.2) if the crew believes they cannot maintain appropriate separation. If the separation shown is larger than the actual separation, it may lead to inadequate separation (OH 6.1, 6.2) or failure to terminate the visual approach when appropriate (OH 8.1). Also see the discussion of errors in the ground speed or closure rate of the selected traffic when erroneous range information is used to derive those rates.	OH 3.1 OH 3.2 OH 6.1 OH 6.2 OH 8.1 OH 8.2
Traffic identification	Fails to display when appropriate. The traffic symbol is displayed but the corresponding traffic identification is not displayed.	This is only of concern for the traffic called by the controller. The crew is unable to use traffic identification information from the controller to identify the traffic on the CDTI. The crew will follow standard visual approach procedures. This is also an obvious equipment failure.	None
	Displays when not appropriate. Traffic identification information is displayed without a corresponding traffic symbol.	This failure is obvious to the crew. Suggests ASA equipment has failed and should not be relied on.	None
	Erroneous information content. Incorrect IDs are shown with one or more traffic symbols, or the crew misreads the IDs or misinterprets the association between IDs and traffic symbols.	Valid IDs may be associated with the wrong traffic symbol. IDs not corresponding to any traffic in the vicinity may be displayed. The only operational hazard is when the ID for the traffic called by the controller is associated with the wrong traffic symbol, potentially leading to misidentification of the traffic (OH 3.2). Otherwise either the called ID is associated with the correct traffic symbol, normal operation, or the called ID does not appear on the display and the crew will follow normal visual approach procedures.	OH 3.2

Required Information	**Failure Mode**	**Effect**	**Contributes to Operational Hazard(s) (see table 2)**
Traffic horizontal velocity vector	Fails to display when appropriate. A velocity vector is not shown for one or more traffic symbols.	The purpose of the velocity vector is supplemental. Since it predicts where the aircraft will be in the future it could be used as a crude prediction of conflict. Lack of this information would not be expected to hinder the crew's performance of EVAppr.	None
	Displays when not appropriate. A velocity vector is displayed that is not associated with any traffic symbol.	This is an equipment failure that will be obvious to the crew.	None
	Erroneous information content. The velocity vector does not correctly indicate the direction of flight of the corresponding aircraft, or crew misinterprets information.	The purpose of the velocity vector is supplemental. Since it predicts where the aircraft will be in the future it could be used as a crude prediction of conflict. Lack of this information would not be expected to hinder the crew's performance of EVAppr.	None
Selected target closure rate or ground speed	Fails to display when appropriate. Although the called traffic is selected on the CDTI, the closure rate or ground speed information is not displayed.	This is an equipment failure obvious to the crew. The additional information is not available to the crew for judging future separation, and the crew must rely on visual observation alone as in the standard visual approach.	None
	Displays when not appropriate.	Equipment error obvious to the crew.	None
	Erroneous information content. The information presented is for a different aircraft than the one highlighted on the CDTI during the selection process.	If the information presented is plausible to the crew, may lead the crew to slow unnecessarily, or to fail to slow when appropriate.	OH 6.1, 6.2

Required Information	Failure Mode	Effect	Contributes to Operational Hazard(s) (see table 2)
	Erroneous information content. Information is presented for the correct aircraft, but the values are incorrect or crew misreads the information.	If the speed is smaller than the true speed, or closure rate higher than the true closure rate, may cause the crew to slow unnecessarily, leading to the inefficiency of a larger than required separation. The crew is unlikely to terminate the visual approach unless the distance to the traffic is shown as being too small also. If the speed is higher than the true speed, or the closure rate lower than the true closure rate, may cause the crew to maintain a higher speed than appropriate (OH 6.1). The crew or controller may terminate the visual approach (events E8 or E9) if the crew is then unable to maintain adequate separation. If the rates are derived by differencing the range measurements, errors in range will correlate with errors in the rates, and the two effects will reinforce each other, with the operational hazards arising from the range errors.	OH 6.1, 6.2
Target selection (crew input)	Entry not made when appropriate. Entry not made by crew, or equipment does not accept or act on the entry. The selected target is not highlighted on the CDTI, and its closure rate or ground speed is not displayed. See those display features for operational hazards.		OH 5.1
	Entry made when not appropriate. Crew makes entry at inappropriate time or accidentally, or equipment spontaneously acts as if an entry was made.	Crew will deselect entry. If occurred without crew action, it is an obvious equipment failure.	OH 5.2
	Erroneous information content. A different aircraft is selected than the one intended by the crew due either to crew error or equipment error.	Crew will correct selection once they note that the wrong traffic symbol is highlighted. Otherwise, crew receives ground speed or closure rate information for the wrong traffic.	OH 5.2

Required Information	**Failure Mode**	**Effect**	**Contributes to Operational Hazard(s) (see table 2)**
	Erroneous information content. The aircraft intended by the crew is selected, but the crew misunderstands which aircraft the controller called as traffic, or the controller called the wrong traffic.		OH 5.3
Selected target highlighting	Fails to display when appropriate, or highlighting not obvious to crew	. This is an obvious equipment problem. Crew does not get confirmation that correct traffic has been selected, so closure rate/ground speed display may be for the wrong aircraft. Crew should not use closure rate/ground speed information or any other information provided as a result of target selection. Also makes it more difficult to re-locate the traffic on the CDTI display in dense traffic during the crew's visual scan, increasing workload.	None, as long as crew does not use closure rate/ ground speed information or any other information provided as a result of target selection
	Displays when not appropriate. A target is highlighted without being selected by the crew.	This is an obvious equipment failure.	None
	Erroneous information content. A different target is highlighted than the one intended by the crew.	Depending on how selection is made and what target is highlighted, the crew may assume that they made an incorrect entry. In any case the crew is likely to try to correct it. If that fails, then it will be obvious that there is an equipment failure.	None
Range reference	Fails to display when appropriate.	This is an obvious equipment problem, as the range reference should always be displayed. This makes it impossible for the crew to use the CDTI to determine horizontal separation. However, the crew should still be able to use the CDTI to assist in identifying the called traffic based on relative range and relative bearing. The crew should still be able to use the CDTI to determine relative altitude and closure rate or ground speed. Therefore there may still be some benefit in using the CDTI as an aid to the visual approach.	None
	Displays when not appropriate.	Meaningless, as the range reference should always be displayed.	N/A

Required Information	Failure Mode	Effect	Contributes to Operational Hazard(s) (see table 2)
	Erroneous information content. The range reference displays at the wrong distance from own aircraft symbol.	The crew may incorrectly estimate the range of the traffic called by the controller. The effect is the same as if all traffic was displayed at the wrong range. This may delay visual acquisition (OH 3.1) if the range reference error is large enough, but this magnitude of error is also likely to result in the crew questioning the accuracy of the CDTI display. Once the clearance for the visual approach has been given, this may lead to maintaining either larger or smaller separation than appropriate. If the called traffic is shown closer than it really is, larger separations than necessary may be maintained. This is inefficient, but no operational hazards result. However, the crew may unnecessarily terminate the visual approach if they cannot maintain the larger separation (OH 8.2). If the separation shown is larger than the actual separation, it may lead to inadequate separation (OH 6.1) or failure to terminate the visual approach when appropriate (OH 8.1).	OH 3.1 OH 6.1 OH 6.2 OH 8.1 OH 8.2